SUBJECT: Ascent of Mars Surface Sample Return (MSSR) Probe - Delta-V Requirements - Case 103-2

DATE: January 5, 1967

FROM: J. J. Schoch

ABSTRACT

A study of Mars ascent trajectories for the Mars Surface Sample Return (MSSR) probe was performed. The results are presented in terms of ΔV, derived from the actual weight ratio of the different stages. The calculations were performed for two atmospheres: the VM-3 and VM-8.

The results are shown in Table 1 and Figure 2. The influence of the Martian atmosphere is very large. The vehicle uses 1500 ft/sec less, when changing from a high density to a low density atmosphere. The large influence of the two atmospheres may be more clearly observed from Figure 3 and 4 showing the trajectory profiles vs time. Increasing the thrust has little effect. The position of the probe relative to the spacecraft is shown in Figure 5.

It is concluded that for this high drag configuration ascent vehicle the performance is greatly affected by the atmosphere.

(NASA-CR-153730) ASCENT OF MARS SURFACE SAMPLE RETURN (MSSR) PROBE: DELTA-V REQUIREMENTS (Bellcomm, Inc.) 12 p

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BELLCOMM, INC.

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MEMORANDUM FOR FILE

INTRODUCTION

The Mars Surface Sample Return (MSSR) Probe is launched from the manned Mars flyby spacecraft approximately 5 days before the spacecraft's arrival at periapsis. It lands on the Martian surface about two hours before the spacecraft's periapsis passage and is launched at such a time as to rendezvous with the flyby spacecraft.

The present memorandum is concerned with the launch trajectory of the MSSR probe. It is assumed that the launch trajectory is planar and lays at launch in the same plane as the flyby spacecraft.

Since the design of the MSSR probe is not yet finalized, the results are presented in the form of total ΔV required from liftoff to rendezvous.

TRAJECTORY DETAILS

The study of the trajectories was based on a three stage vehicle as described on Table 2 of Reference 1. The weight of the stages is described therein as follows:

STAGE	ENGINE & STRUCTURE WEIGHT (LBS)	PROPELLANT WEIGHT (LBS)
Stage 1	230	2660
Stage 2	82	666
Stage 3	24	148

The trajectory itself follows the following profile.

During the first stage flight, the vehicle rises vertically for 10 sec at which time it is tilted for a predetermined length of time and follows a so-called gravity turn trajectory for the remaining duration of the stage. During the

[redacted]

second and third stage the vehicle's pitch angle follows a linear tangent relation, i.e.,

$$\tan \Psi = A+Bt$$

where Ψ = vehicle pitch angle

A = initial pitch

B = pitch rate

t = time from start of second stage.

The linear tangent law is a very good approximation to the optimum path for earth launches to a circular trajectory. It is not necessarily the optimum path for the present application but was assumed to be a sufficiently good approximation.

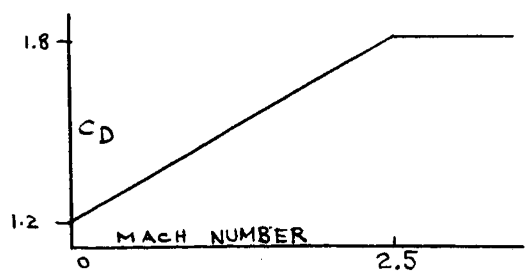
Between the second and third stage a coasting period is inserted which may be used for final guidance adjustment.

The thrust was originally selected in such a manner as to give approximately the following thrust-to-weight ratios for the different stages:

1st Stage	2nd Stage	3rd Stage
1.7	2.1	1.9

To determine the influence of the value of the thrust on the trajectory, it was increased for all stages by 25 and 50%. For convenience the three values of thrust will be referred to as low, medium, and high respectively.

During first stage flight, the vehicle experiences a drag force which was computed, based on the following assumption for the drag coefficient as a function of Mach number:



The first stage frontal area was assumed to be 22 ft^2. Drag was neglected during second and third stage burn.

Two different atmospheres were used in the analysis: the JPL atmospheres VM-3 and VM-8 (Reference 2). These two atmosphere models have about the same surface density, but at high altitudes the density is orders-of-magnitude greater for VM-3 (see Figure 1).

Trajectories were run for different rendezvous points along the spacecraft hyperbola in order to determine the optimum which was found to be in the neighborhood of $3 - 4 \times 10^6$ ft altitude. For each altitude the optimum kick angle, i.e., the kick angle giving the highest payload was determined; thus, each run was optimized for kick angle and rendezvous altitude.

All runs were initially made for a spacecraft periapsis altitude of 118.6 nm and a V_∞ = 28250 ft/sec. For one case the calculation was repeated for a periapsis altitude of 300 nm.

RESULTS AND CONCLUSIONS

The results of the trajectory computations are given on Table 1 and summarized in Figure 2. Reductions in theoretical ΔV are presented rather than payloads.

The bar chart on the leftside refers to the high density atmosphere VM-3, the one on the right to the low density atmosphere VM-8.

The case of low thrust for the high density atmosphere (VM-3) was selected as a reference. It requires a theoretical velocity increment of ΔV = 36973 ft/sec. In Figure 2 this corresponds to a ΔV decrease of zero. The difference in ΔV due to switching from the high to the low density atmosphere is of the order-of-magnitude of 1500 ft/sec. For the vehicle under consideration, this corresponds to a reduction of gross weight to payload ratio from 114 for the VM-3 atmosphere to 88 for the VM-8 atmosphere. The effect of the two different atmospheres on the ascent trajectory is even more apparent on Figures 3 and 4. Figure 3 shows a plot of vehicle velocity and dynamic pressure as a function of first stage burning time. Figure 4 shows a plot of flight path angle and altitude as a function of first stage burning time. It may be observed that the trajectory in the VM-3 atmosphere is much steeper and that the vehicle experiences substantially larger dynamic pressures (almost 3 times).

It may also be noted that at the end of the first stage the dynamic pressure is still 2 lb/ft^2 for VM-3. As stated elsewhere, drag was neglected during second and third stage burn. Had it been considered the ΔV difference would even be larger.

The drag loss in terms of ΔV was computed by integrating Drag/Mass vs time. The result showed a ΔV loss of 1050 ft/sec for the VM-3 atmosphere and only 155 ft/sec for the VM-8 atmosphere.

An increase in thrust of 25 and 50% for all three stages does not significantly change the ΔV requirement but its effect is a little larger on the low density atmosphere (about 300 ft/sec compared to 130 ft/sec when going from the low thrust to the high thrust).

Using half the drag for the basic case provided a ΔV reduction of about 650 ft/sec. Changing the spacecraft periapsis altitude from 118.6 to 300 nm added about 425 ft/sec to the ΔV require (-decrease on Figure 2). The trajectory of the MSSR probe relative to the spacecraft is shown in Figure 5.

It is concluded that for this high drag configuration ascent vehicle the performance is greatly affected by the atmosphere.

The results indicate that a high drag, low structural weight configuration may not be the best choice for this mission.

J J Schoch

1013-JJS-csh J. J. Schoch

Attachments:
References
Figures 1 - 5
Table 1

Copy to
(See next page)

Copy to
Messrs. W. C. Beckwith - NASA/MTP
J. R. Burke - NASA/SAS
P. E. Culbertson - NASA/MTL
J. H. Disher - NASA/MLD
F. P. Dixon - NASA/MTY
R. W. Gillespie - NASA/MTY
E. Z. Gray - NASA/MT
M. Gruber - NASA/MTY
W. L. Haberman - NASA/MTY
E. W. Hall - NASA/MTS
D. P. Hearth - NASA/SL
T. A. Keegan - NASA/MA-2
D. R. Lord - NASA/MTD
M. J. Raffensperger - NASA/MTE
L. Reiffel - NASA/MA-6
A. D. Schnyer - NASA/MTV
W. B. Taylor - NASA/MLA
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C. Covington - MSC/ET23
J. Funk - MSC/FM8
R. G. Gonzalez - MSC/ET25
R. C. Kennedy - MSC/ET25
G. C. Miller - MSC/ET23
M. A. Silveira - MSC/ET25
W. E. Stoney, Jr. - MSC/ET
J. M. West - MSC/AD

R. J. Harris - MSFC/R-AS-VP
B. G. Noblitt - MSFC/R-AERO-DPF
H. F. Thomae - MSFC/R-AERO-X
F. L. Williams - MSFC/R-AS-DIR

J. P. Claybourne - KSC/EDV4
R. C. Hock - KSC/PPR2
N. P. Salvail - KSC/MC

G. M. Anderson
J. P. Downs
D. R. Hagner
P. L. Havenstein
J. J. Hibbert
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R. V. Sperry
T. H. Thompson
J. M. Tschirgi
R. L. Wagner
All Members, Division 101
Department 1023
Central Files
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REFERENCES

1. Macchia, D., Skeer, M. H., and Wong, J.: Conceptual Design of Structural and Propulsion Systems for an MSSR Rendezvous Vehicle, Bellcomm Memorandum for File, August 5, 1966.

2. Atmosphere Data to Alter Voyager Design, Aviation Week and Space Technology, November 22, 1965, pp. 66-69.

ATMOSPHERE,	THRUST,	DRAG,	COAST between, 2nd & 3rd Stage (sec.)	Spacecraft Periapsis passage altitude (n.miles)	ΔV (ft/sec)
VM3	LOW	FULL	60	118.6	36,974
VM3	LOW	FULL	0	118.6	36,907
VM3	MEDIUM	FULL	60	118.6	36,924
VM3	HIGH	FULL	60	118.6	36,846
VM3	HIGH	HALF	60	118.6	36,192
VM3	LOW	FULL	60	300	37,399
VM8	LOW	FULL	60	118.6	35,504
VM8	LOW	FULL	0	118.6	35,461
VM8	HIGH	FULL	60	118.6	35,192

TABLE 1 Delta V Requirements

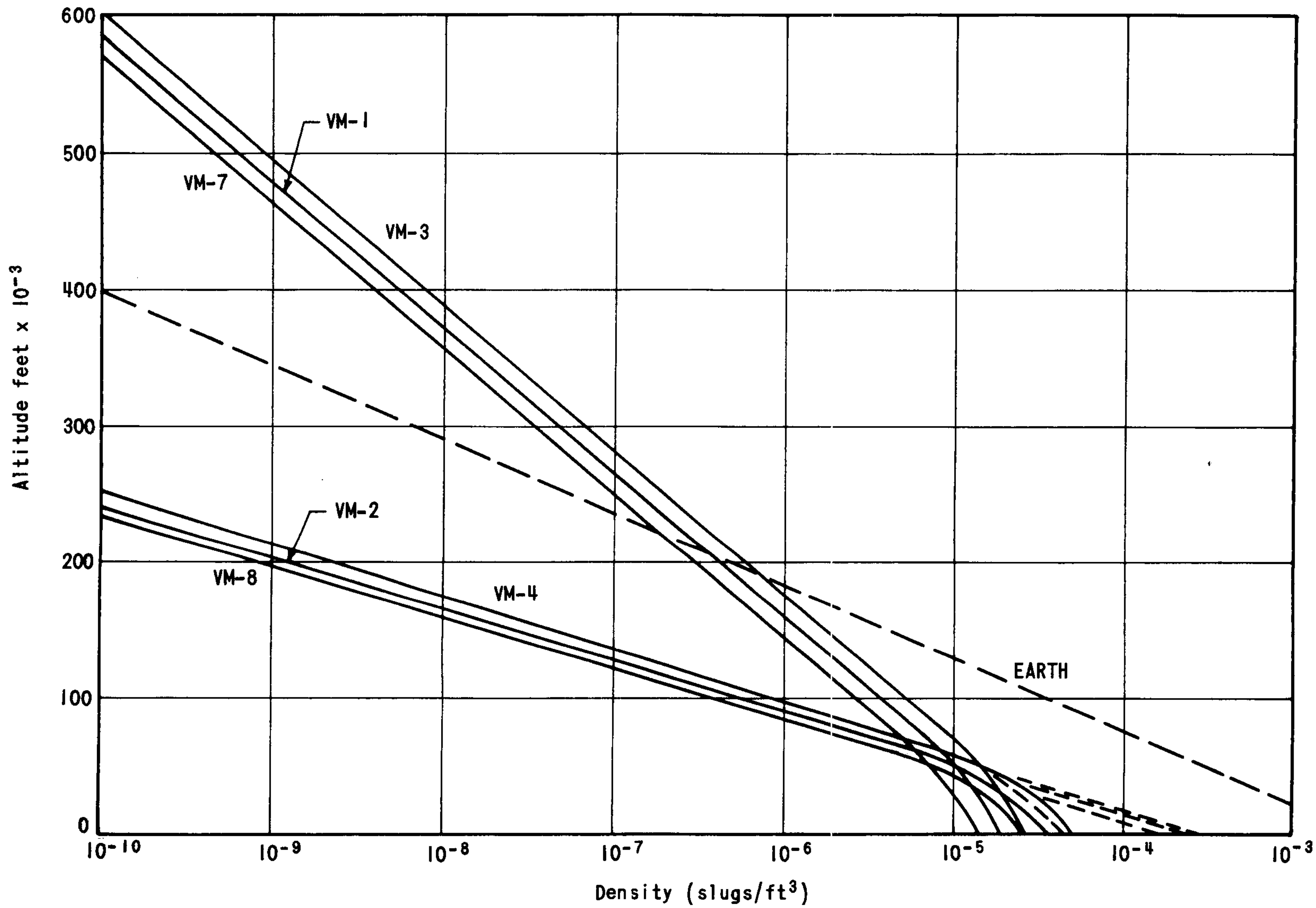


FIGURE 1 - JPL - MARS MODEL ATMOSPHERES

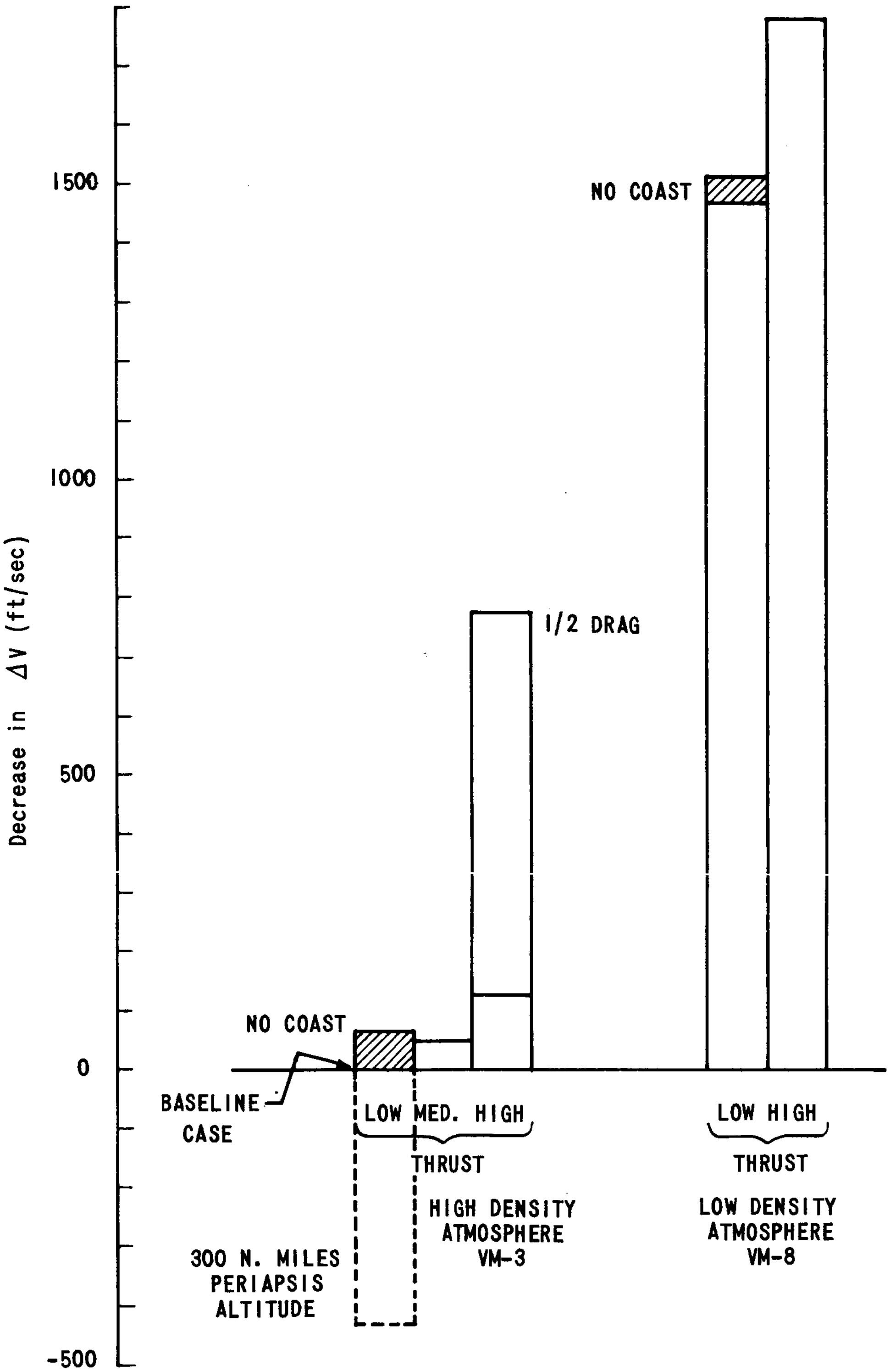


FIGURE 2 - DECREASE IN ΔV FOR VARIOUS CONDITIONS

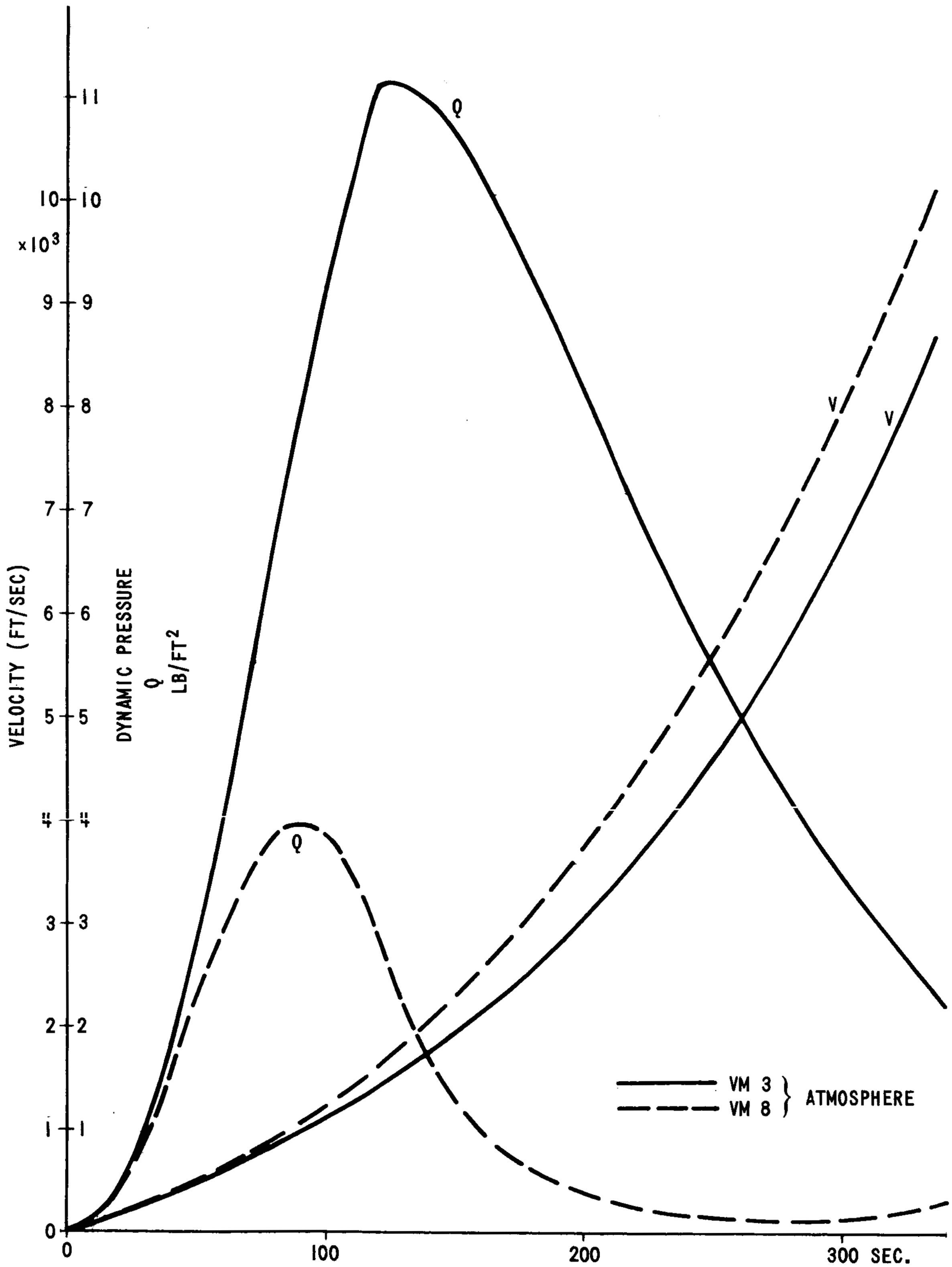


FIGURE 3 - COMPARISON OF TIME HISTORY OF VELOCITY AND DYNAMIC PRESSURE DURING FIRST STAGE FLIGHT

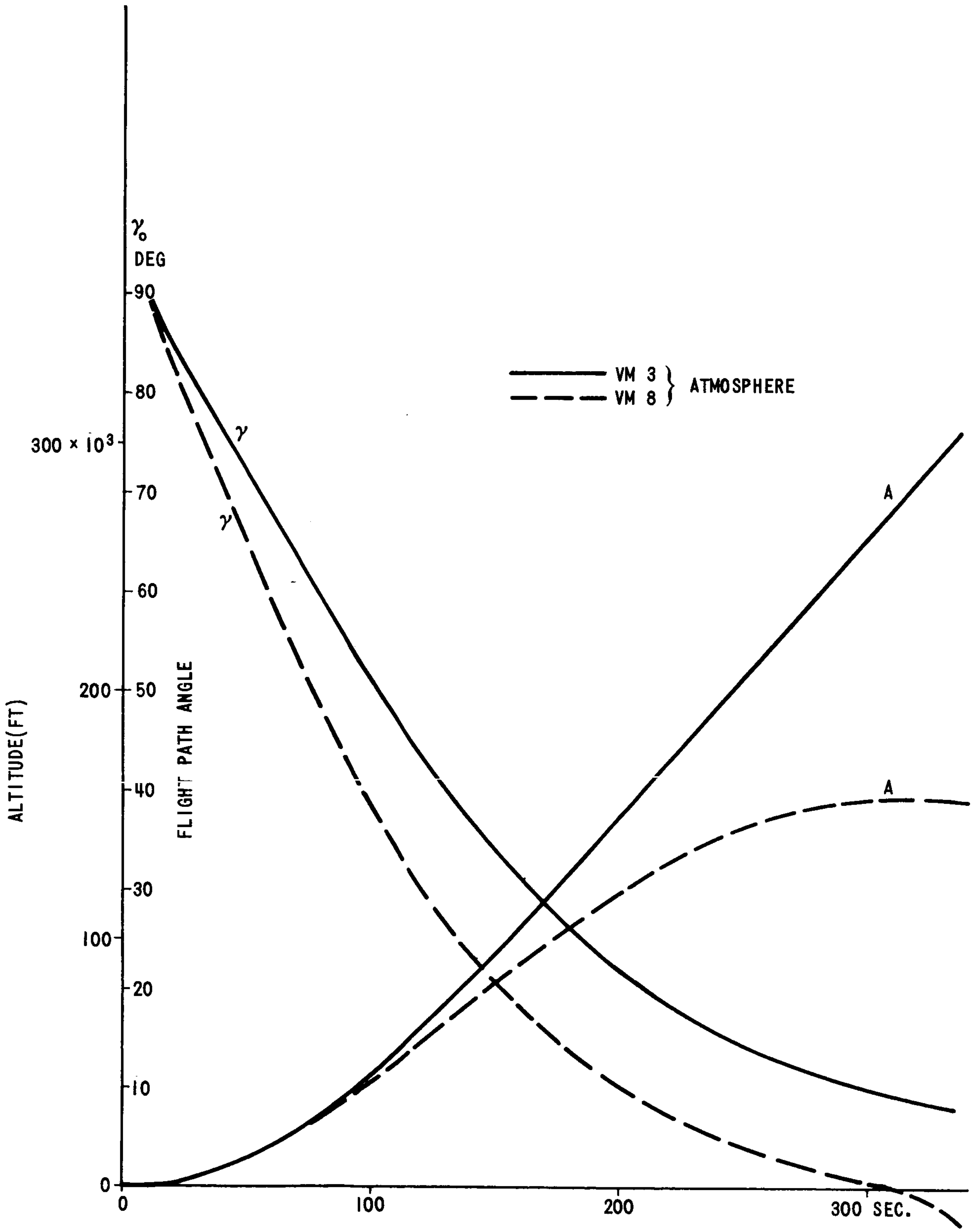
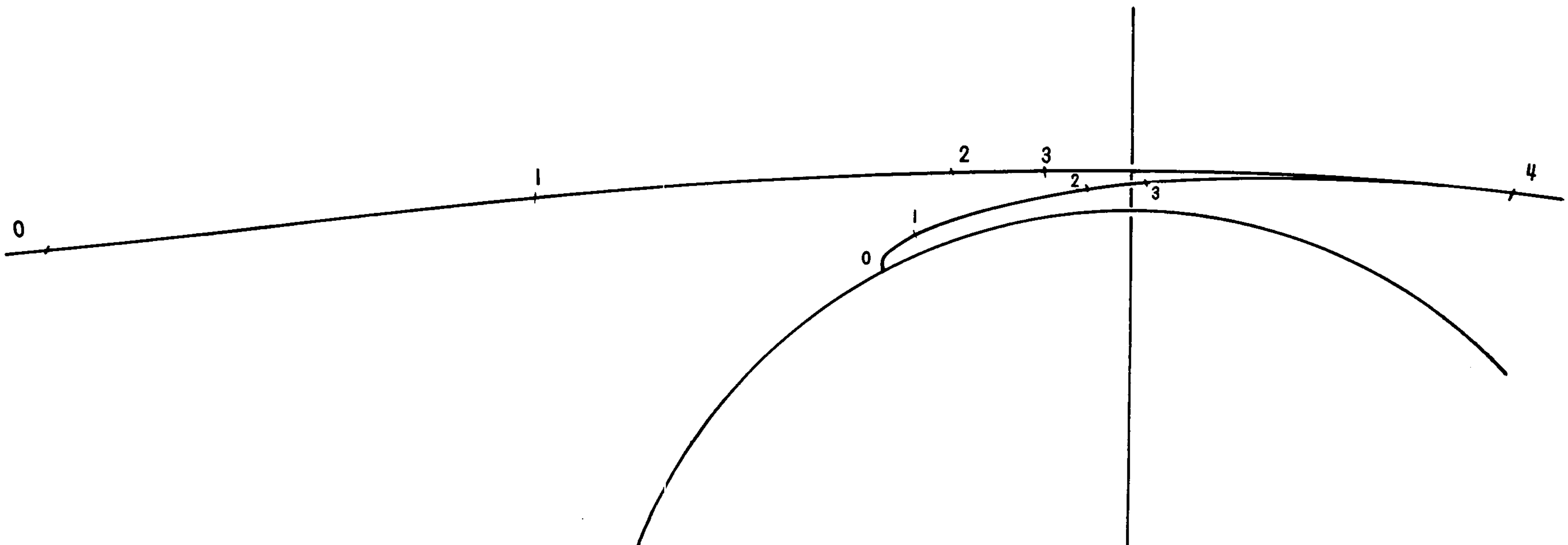


FIGURE 4 - COMPARISON OF TIME HISTORY OF FLIGHT PATH ANGLE AND ALTITUDE DURING FIRST STAGE FLIGHT



SYMBOL	EVENT	TIME RELATIVE TO SC PERIAPSIS PASSAGE	DISTANCE BETWEEN SC AND PROBE
0	MSSR LIFT OFF	12 MIN	2900 N. MILES
1	CUTOFF STAGE 1	6.5 MIN	1340 N. MILES
2	CUTOFF STAGE 2	2 MIN	475 N. MILES
3	IGNITION STAGE 3	1 MIN	356 N. MILES
4	CUTOFF STAGE 3	4 MIN	0 N. MILES

FIGURE 5 - RELATIVE FLIGHT PATH OF PROBE AND SPACECRAFT